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REFERENCE MANUAL FOR THE SOUTHERN RESEARCH INSTITUTE PARTICLE SIZE ANALYZER

Southern Research Institute
Birmingham, Alabama

12 October 1959

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For

U. S. PUBLIC HEALTH SERVICE

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SOUTHERN RESEARCH INSTITUTE
2000 9th Avenue S. Birmingham 5, Alabama

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REFERENCE MANUAL FOR THE SOUTHERN RESEARCH INSTITUTE PARTICLE SIZE ANALYZER

SECTION I. INTRODUCTION

The particle size analyzer described in this manual was developed under Contract No. SAph 70964 with the U. S. Public Health Service. The instrument is composed of a particle counter and a pulse-height analyzer. It is portable and battery operated and is designed to measure particle size distributions in atmospheric aerosols and in other suspensions of solid particles or liquid droplets in gases.

The instrument covers the range of particle sizes from 0.3 micron to 4 microns, diameter. A 15-channel galvanometer simultaneously indicates the total concentration of particles in the above range and also the concentrations in each of 12 size channels. The particle counter can be used alone to obtain indications of particle concentrations above a given size, this minimum size being adjustable from 0.3 micron to 2 microns.

SECTION II. OPERATING PROCEDURES

The particle size analyzer, shown in Figure 1, is composed of the particle counter on the left and the pulse-height analyzer on the right.

Operating the Particle Counter Alone

To operate the particle counter alone, disconnect the cable to the pulse-height analyzer and turn particle counter switch S1 to the "Zero" position. Then turn S2 to the "On" position and adjust potentiometer R1, located on the rear of the case, to zero the meter. Next, set the discriminator potentiometer R2 to the desired minimum particle size. For high concentrations set the switch S1 to the "100 pps" position and set the dilution valve at a dilution factor high enough to prevent the meter from reading off scale. For lower concentrations the dilution valve can be set to a lower factor, or the selector switch S1 can be set to the "10 pps" position. For very low concentrations the selector switch should be set in the "600 p" position for 1 minute and then switched to the "Hold" position.

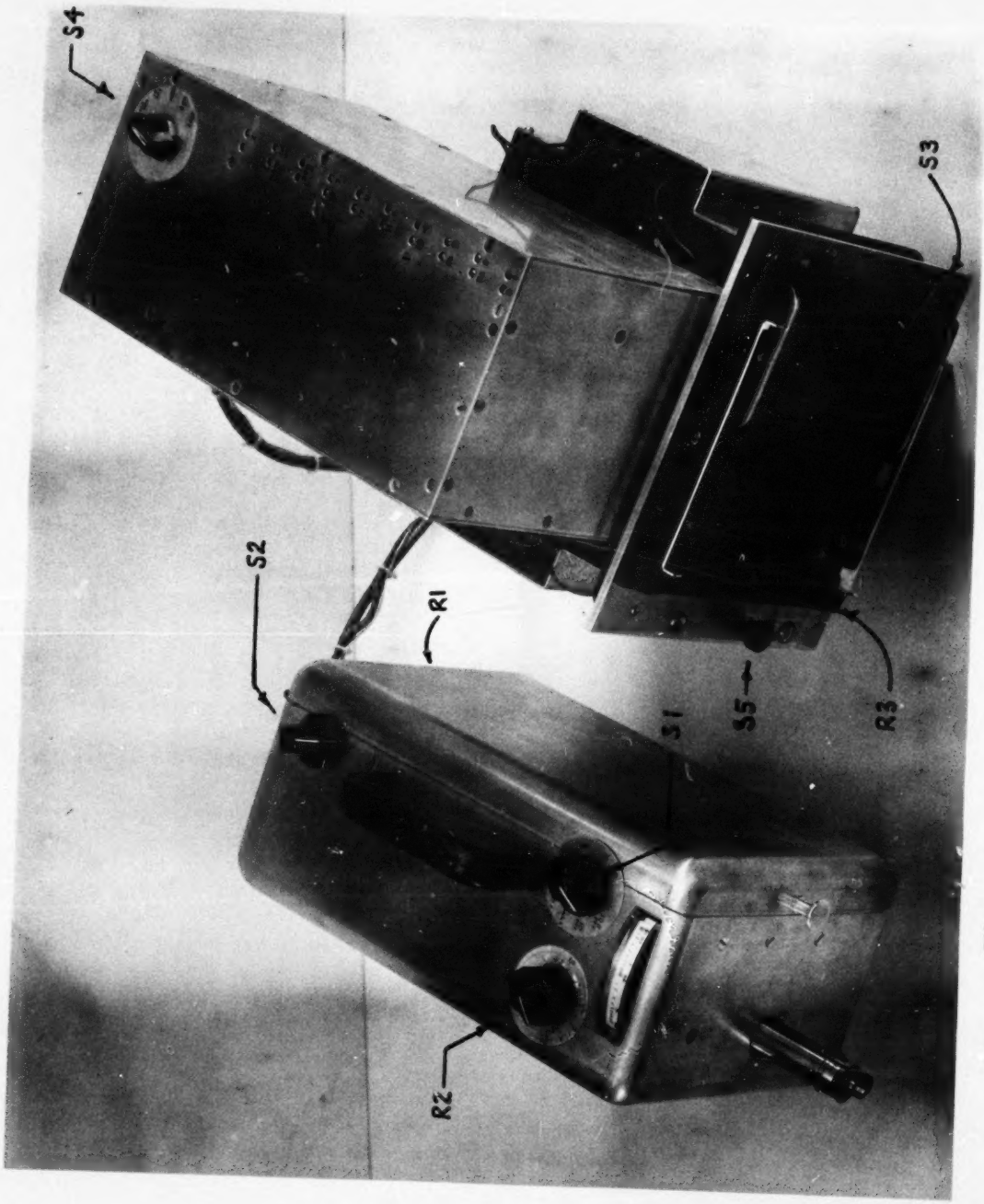


Figure 1. View of the Particle Size Analyzer.

In the "100 pps" position the full-scale meter reading corresponds to 10 million particles per cubic foot, and true concentration is the meter reading multiplied by the dilution factor. If the selector switch is in the "10 pps" position, the true concentration is the meter reading times 0.1, times the dilution factor. With the selector switch in the "600 p" position, the full-scale meter reading corresponds to 1 million particles per cubic foot when read after 1 minute. If read after periods other than 1 minute. the full-scale value is inversely proportional to reading time. Reading times of more than a few minutes will not produce accurate measurements because of drift and leakage. As before, the concentration readings should be multiplied by the dilution factor for true concentration.

Operating the Pulse-Height Analyzer

To obtain particle size distributions, connect the pulse-height analyzer to the particle counter through the connectors provided. This should be done with the particle counter off because the analyzer power is controlled by the particle counter switch. To operate the instrument, begin by turning on the light switch S3, located on the front of the galvanometer panel. By means of potentiometer R3, set the light to the lowest usable intensity to conserve lamp and battery life. Next, set the selector switch S4, located on top of the analyzer, to the "Zero" position. Turn the particle counter on and after a few minutes zero the light spots of the galvanometer with the controls located on the left side of the analyzer. The first spot indicates dilution and does not have a zeroing potentiometer. The second spot indicates concentration in the total channel and is zeroed with the "Total" potentiometer. The third through the fourteenth spots indicate concentrations in channels one through twelve, respectively. The scale for dilution factor is on the left. The dilution factor should be set at either 10 or 1.

To obtain a particle size distribution the selector switch can be switched to the "100 pps" position, the "10 pps" position, or the "600 p" position. These selector switch positions are related to concentrations in the same manner as in the particle counter; however, each reading is concentration per 0.1 micron of channel width. As before, the galvanometer reading must be multiplied by the dilution factor. To record a size distribution display, set the selector switch to the "Hold" position. Turn off the galvanometer lamp and insert the Polaroid film holder into the Graflok back. The film should be exposed and developed according to the Polaroid instructions, with the red push button S5, on the

front of the galvanometer, acting as a shutter control. The push button turns on the lamp for as long as the button is held in. Records can also be made using conventional film. Ansco Superpan Press Film Pack, or equivalent, is recommended. The exposure times should be about one second for both the Superpan Press film and the Polaroid type 53, with exact exposure time depending on lamp intensity. Readings will remain steady in the "Hold" position for several minutes.

The particle size channel width varies approximately logarithmically with particle size as shown in Figure 2, and the calibration of the channels is varied with channel width to give millions of particles per cubic foot per 0.1 micron of channel width. The galvanometer spots are located horizontally in the center of the size range recognized by each channel. This scheme results in an approximately log-log distribution curve.

SECTION III. PRINCIPLE OF OPERATION

The particle size analyzer detects particles photoelectrically as outlined in the block diagram of Figure 3. Air is drawn through a small tube into an illuminated zone, then exhausted from the instrument. As each particle in the air passes through the illuminated zone, it scatters light to a sensitive phototube. The phototube delivers very little current when there is no particle illuminated because its lenses restrict its angle of acceptance to a dark background. But when a solid particle or a droplet of liquid passes through the light, the phototube delivers a short pulse of current of about one-millisecond duration. The general relationship between pulse height and particle size is illustrated in Figure 2.

By means of the dilution valve the flow system provides for adding clean air to the sample aerosol and discarding the excess mixture without subjecting the sample to sharp changes in direction, which would trap some of the larger particles. The sample is drawn through one inlet tube, and filtered air comes through the other. These flow streams can pass straight through the valve and out their corresponding outlet tubes. But if the inlet stem is rotated with respect to the outlet stem, the two outlet tubes will receive portions of the flow from each inlet tube. Thus, in the sample stream that goes through the dust counter some clean air

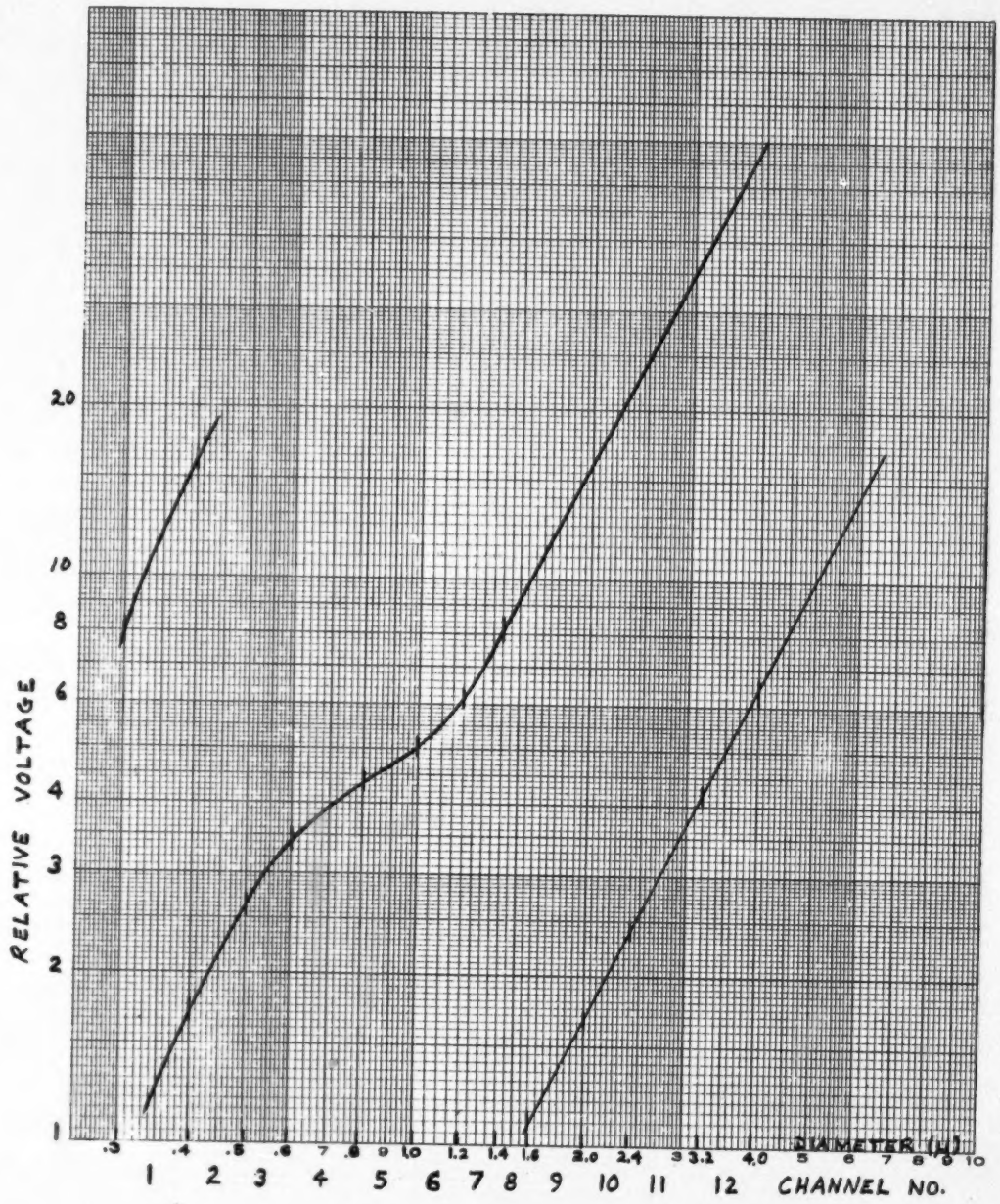


Figure 2. Relative Voltage Versus Particle Size.

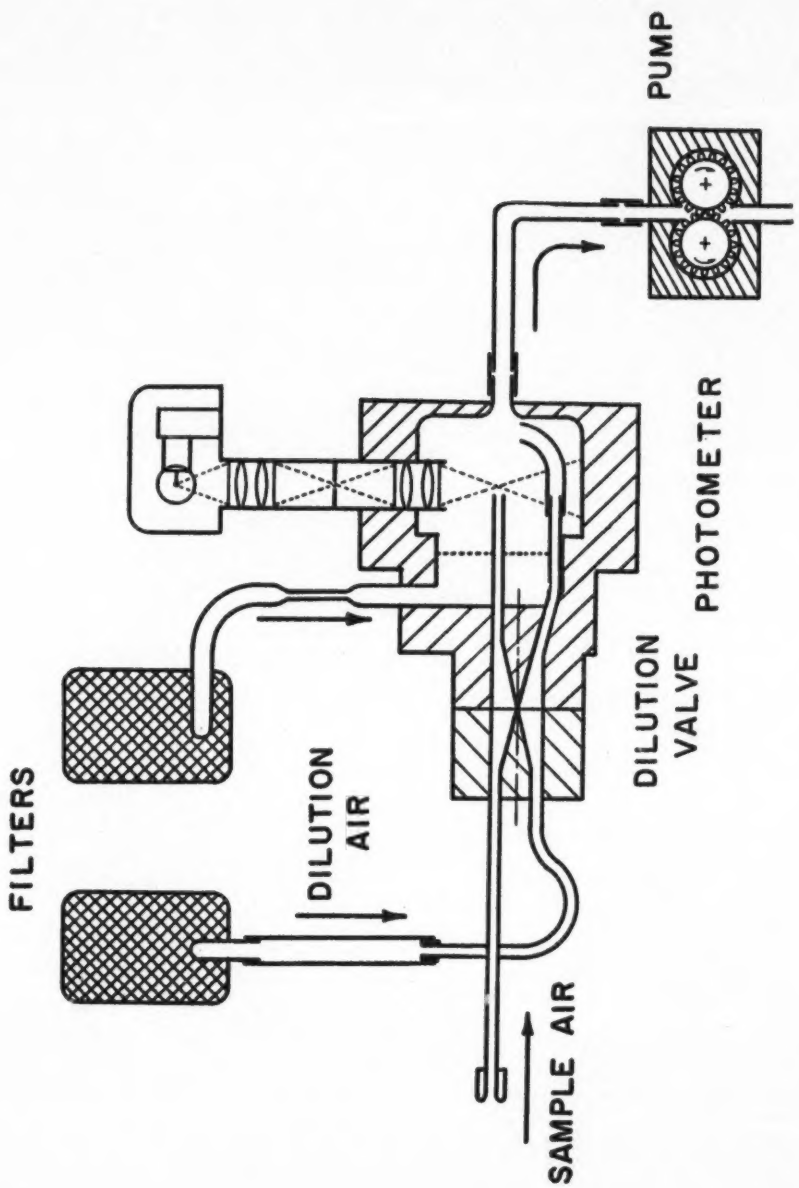


Figure 3. Flow System.

will be mixed in, and similarly some dusty sample air will be directed into the bypass stream. Though the dilution factor can theoretically be infinite, the scale is calibrated at zero dilution (a dilution factor of 1) and a 9:1 dilution (a dilution factor of 10).

The electronic system of the particle counter is shown within the dash lines of Figure 4. Pulses produced by the phototube at "a" are amplified by the amplifier at "c" and are applied to the discriminator at "d." The discriminator produces an output pulse for each incoming pulse above an adjustable minimum. These pulses are amplified and then counted at "f." A current proportional to the logarithm of the number of pulses is indicated by the meter at "g." The instrument can be set to read a total number of pulses occurring over a given period up to several minutes or it can be set to read the pulse rate. Two signals to the pulse-height analyzer are obtained at "b" and "e."

The pulse-height analyzer will divide the input pulses into twelve amplitude groups with boundaries and sensitivities adjustable to cover the particle size range of 0.3 to 10 microns diameter. A thirteenth channel counts the total number of particles recognized by the most sensitive discriminator. The electronic system of the pulse-height analyzer is shown in Figure 4. Pulses from the photometer are amplified by the amplifier at "i" and applied to the peak storage circuit at "n." The pulses are also connected to the main discriminator at "j," which produces an output pulse of uniform height for each significant input pulse. The output pulse goes to the delay circuit at "k," which delivers a pointed pulse to the gate generator at "l." Uniform gate pulses of adjustable duration occur just after each input pulse terminates. They are amplified at "m" and go to the thirteen gates in the discriminator channels at "s." Also generated at "l" is a positive pulse, which is amplified by the amplifier at "p" and goes to the switch circuit at "o." The switch circuit returns the peak storage circuit voltage to ground. The output of the peak storage circuit is given power amplification at "q" and is then presented to the first nine discriminators at "r." Similar pulses are applied to the last five discriminators from the peak storage circuit at "w." A reference voltage at each of the discriminator circuits determines the pulse amplitude required to fire that discriminator and thus sets the minimum particle size of the channel. The maximum particle size counted in each channel is set by providing that the firing of each discriminator after the first closes the gate of the preceding channel.

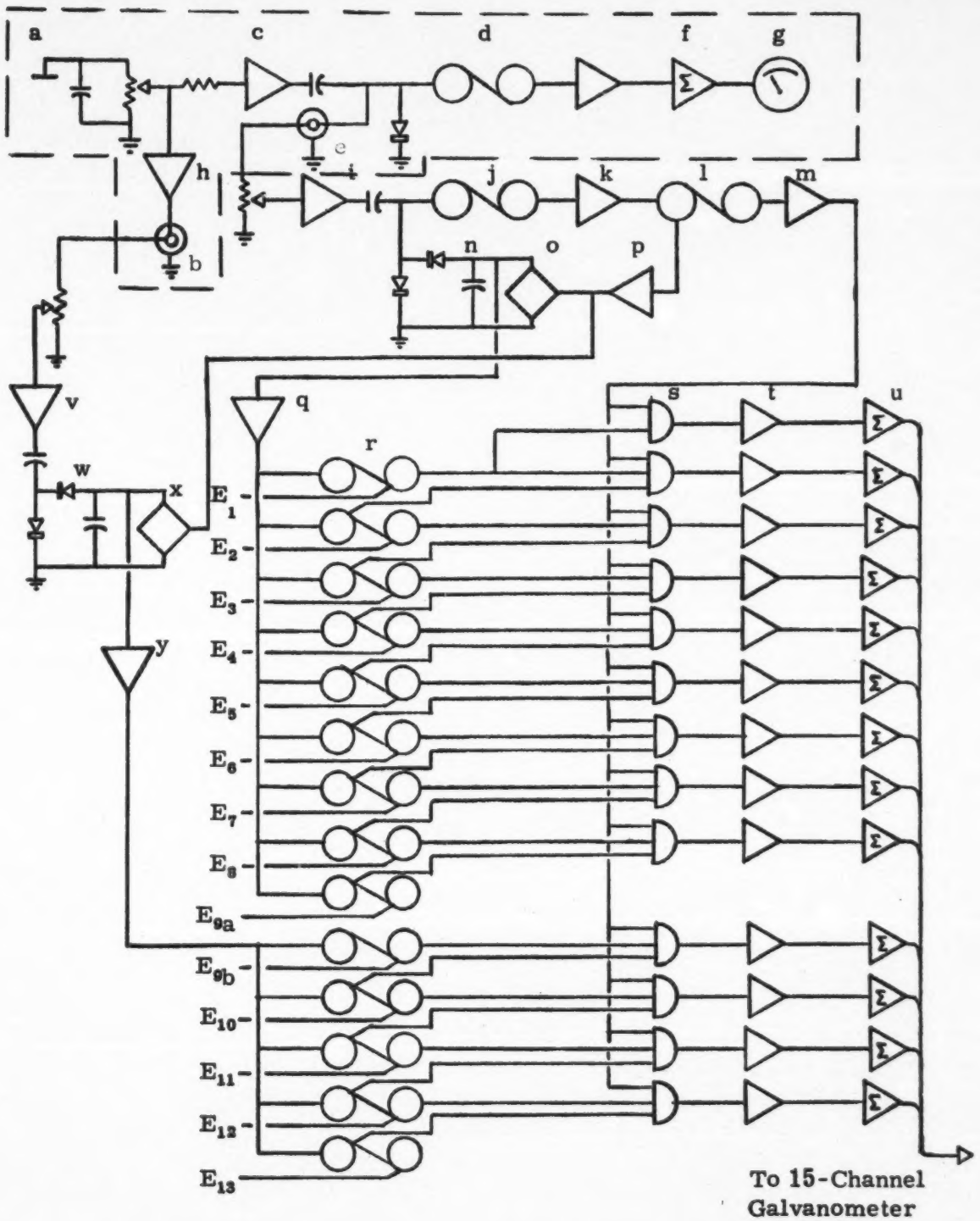


Figure 4. Block Diagram of the Particle Size Analyzer Circuits.

Inputs from the photometer are taken from both "e" and "b." The input from "b" is attenuated with respect to that from "e" so that, when the amplifier at "i" saturates, the amplifier at "v" is delivering its minimum detectable signal. The gate at "s" allows only one channel to count any given pulse. The pulses that pass an open gate are amplified and then counted by the counting circuit at "u," which then provides an output voltage proportional to the logarithm of the number of pulses it receives.

SECTION IV. THE FLOW SYSTEM

The flow system diagramed in Figure 3 can be traced in the photograph of Figure 5. The small gear pump is located on the door chassis of the particle counter and is driven by the modified Brailsford type AG motor. The pump draws sample air from the probe that projects from the front of the counter. It draws dilution air and photometer body air from the two filters located on the body chassis. The body air surrounds the sample air tube entering the photometer body and prevents dispersion of the particles as they pass through the body. At zero dilution setting, the sample air passes directly through the center tube into the photometer body, and the dilution air passes through the bypass tube to the outlet and to the pump. At full dilution this situation is reversed. At dilution settings between these two extremes, various portions of sample and dilution air flow through the two tubes; however, the total flow in each tube remains constant.

The pump motor speed is constant with variations in motor voltage and load; therefore, the pump provides a constant draft on the system. Small adjustments in the flow rate of sample air can be accomplished by changing the flow of the body air with a valve located in the body air line or by adjusting the governor on the motor. The body air setting must be above a certain minimum determined by the point at which particles do not flow directly out of the photometer body but begin to fill the chamber. The condition of the stream can be observed by allowing thick cigarette smoke to be drawn through the sample probe. The maximum setting of the body air is the point at which turbulence occurs. The sample air flow has been set at 17 cubic centimeters per minute with a draft of 0.2 inch of H_2O.

The flow rate was set at 17 cubic centimeters per minute to obtain full-scale reading of concentration of ten million particles per cubic foot

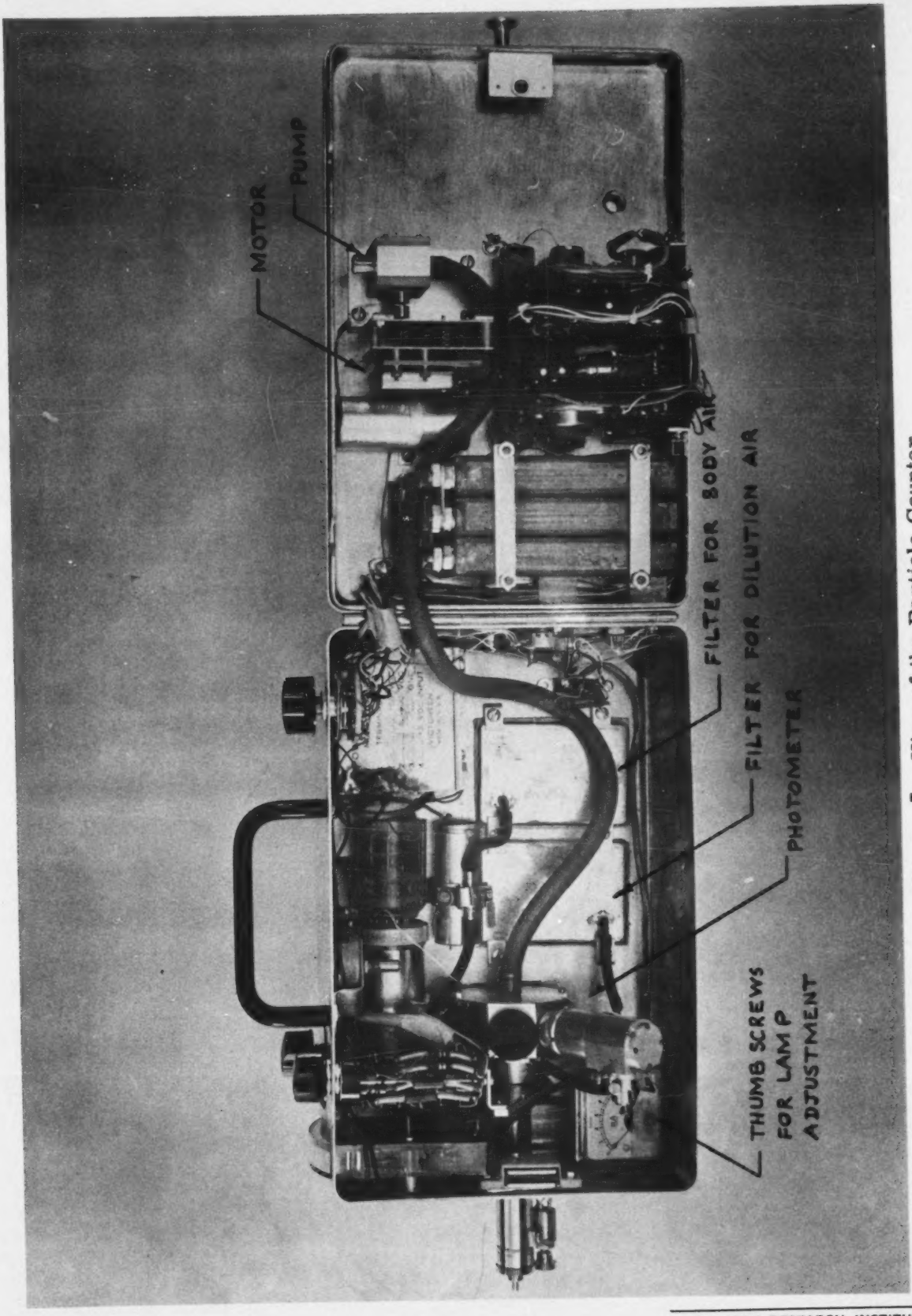


Figure 5. View of the Particle Counter.

undiluted. This was based on a full-scale reading of 100 pulses per second in accordance with the following computation:

$$\text{Flow} = \frac{\text{Pulse Rate}}{\text{Concentration}}$$

$$= \frac{100 \text{ pps} \times 60 \text{ s/m} \times 28.3 \text{ l/cf} \times 10^3 \text{ cc/l}}{10 \times 10^6 \text{ p/cf}}$$

$$\text{Flow} = \underline{17 \text{ cc/min}}$$

SECTION V. THE OPTICAL SYSTEM

The optical system is shown schematically in Figure 6. It consists of an octagonal-shaped photometer body to which are attached a phototube, an illuminator, and a light-intensity detector. The phototube is mounted at the top of the photometer body and is connected to the body by means of a lens tube, which collects the scattered light and focuses it upon the phototube element. The illuminator is connected to the photometer body at an angle of 135 degrees from the phototube. It consists of a PR-3 flashlight lamp, located in front of a spherical mirror, and a lens tube containing 5 lenses. A schematic of this lens system is shown in Figure 7. The light-intensity detector is a silicon photocell located opposite the illuminator and connected to a milliammeter located beneath the photometer. When the illuminator is properly adjusted, the meter should read 0.625 milliamps. The meter will give indications of aging and maladjustment of the lamp.

The lamp should be installed so that its filament is on the centerline of the lens tube and located at the focal point of both the mirror and the first condensing lens. The filament should be transverse to the axis of the lens tube. To accomplish these adjustments, three thumb screws are located on the lamp housing. Two of these, located in the body of the lamp housing, allow translational adjustments. The third, located on a collar around the lamp body, allows vertical adjustment of the lamp. These thumb screws are shown in Figure 5. The filament in some of the PR-3 lamps may be too far off center to be aligned with the thumb screws. It will usually be possible to select usable lamps by visual inspection.

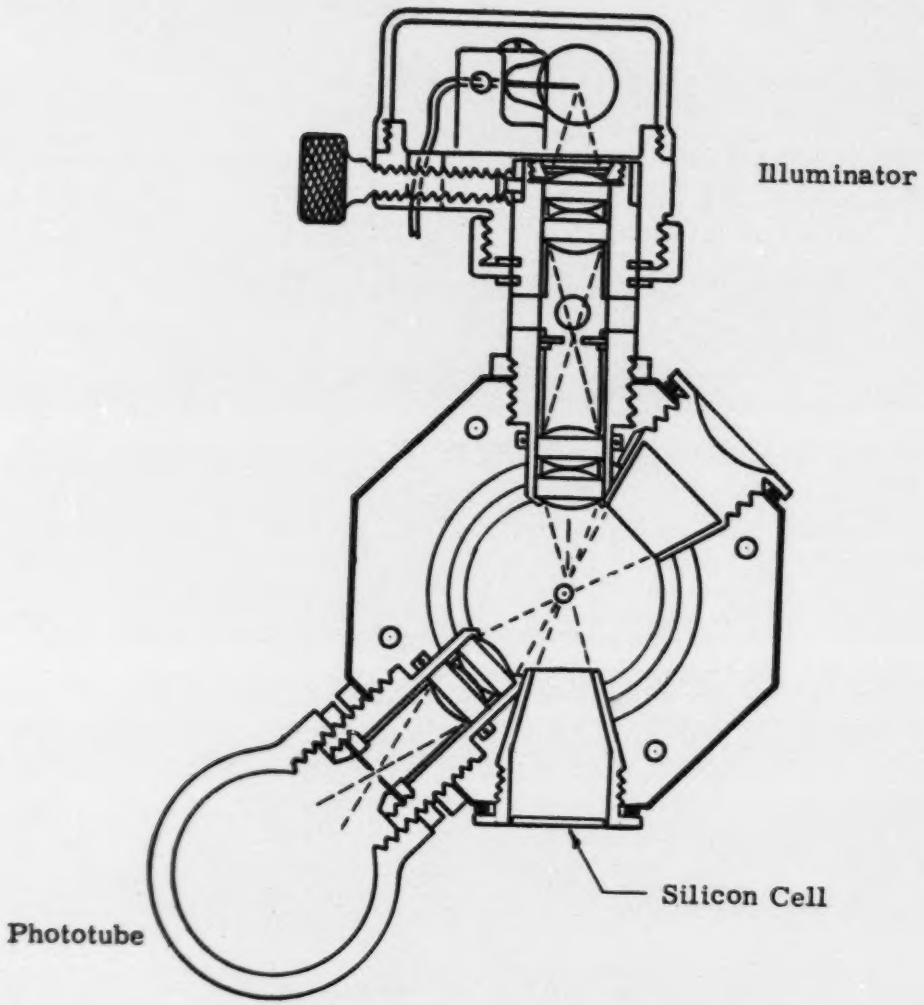


Figure 6. Functional Drawing of the Photometer.

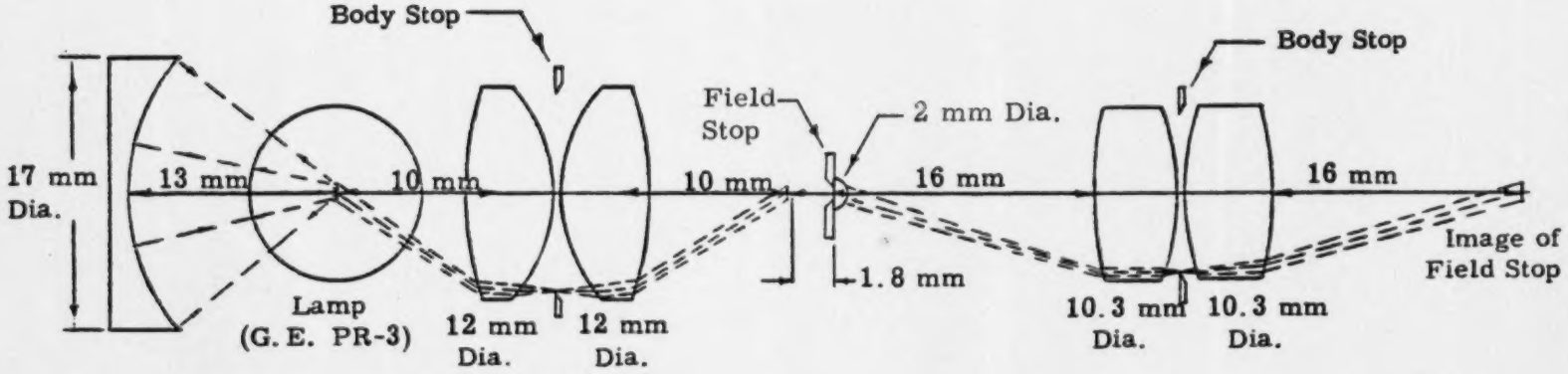


Figure 7. Illumination System.

SECTION VI. THE ELECTRONIC SYSTEM

Particle Counter

The electronic circuit of the particle size analyzer is shown in the block diagram of Figure 4 and is discussed generally in Section III. The circuit of the particle counter, enclosed in the dashed lines of Figure 4, is shown in detail in Figure 8. The amplifier, "c," is composed of seven transistors and has a gain of approximately 30. It has high internal feedback to provide an input impedance of 12 megohms. The first stage is an NPN emitter-follower and is followed by 2 cascaded stages of PNP amplifiers, temperature stabilized by a 1-K thermistor. The next two stages are cascaded NPN amplifiers, stabilized by two parallel 100-K thermistors in the base of the first stage and a 1-K thermistor in the base of the second stage. The last stage is a complementary emitter-follower providing low output impedance to the peak storage circuit. In addition to the feedback of each of the internal amplifiers, feedback is provided from the output to the input through the 22-K resistor.

The output of the amplifier is fed through the switch S1 to the discriminator circuit composed of three PNP transistors. Transistor Q1 provides a constant current for the emitter-coupled clipper circuit composed of Q2 and Q3. Q3 is normally conducting, and the voltage of its collector is -6 volts. The base voltage of Q3 is adjustable and is taken from the reference circuit, which includes a 1-K sensistor for temperature compensation. The emitters of both transistors are held at the base voltage of Q3. When a negative voltage is applied to the base of Q2 causing it to swing below its emitter voltage, Q2 begins to conduct and Q3 cuts off due to coupling through the 0.2-microfarad capacitor. When the negative voltage is removed from the base of Q2, the transistors return to their stable states. The discriminator thus provides an output pulse of constant amplitude for each input pulse greater than the reference setting.

The output of the discriminator is taken from the collector of Q3 and goes to an emitter-follower, Q4. The negative pulse from Q4 is applied through the two forward diodes to the amplifier, Q5. The diodes eliminate noise pulses by presenting a high impedance to all pulses below 0.8 volts. The discriminator pulse applied to Q5 is sufficient to cause saturation of that transistor and produce a 12-volt pulse at its collector. Power gain with unity voltage gain is provided by the complementary emitter-follower used to drive the counting circuit.

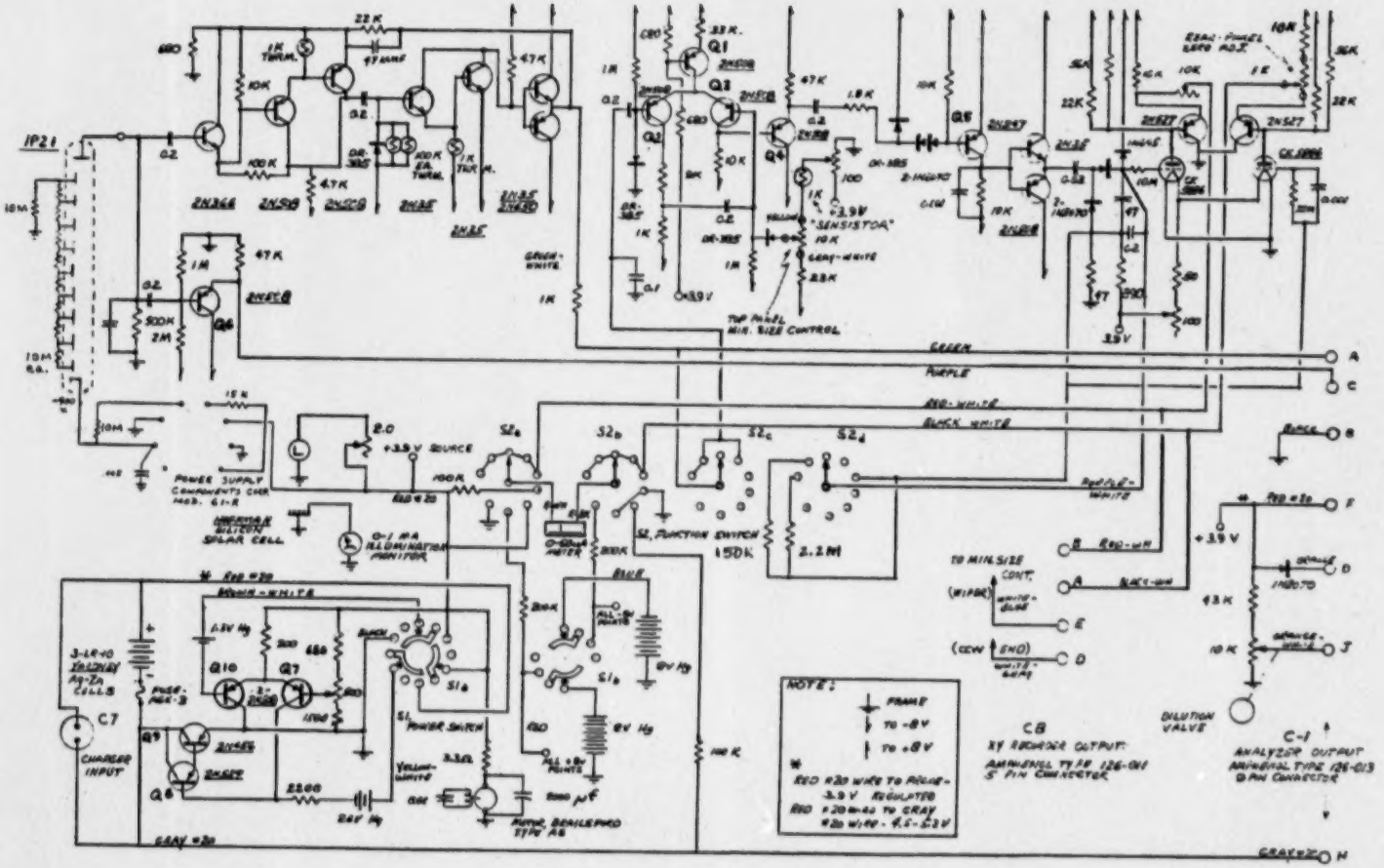


Figure 8. Circuit of the Particle Counter.

The counting circuit is composed of a diode pump counter and a logarithmic amplifier. The diode pump circuit allows a fraction of the incoming pulse to be applied to the 47-microfarad capacitor and prevents the capacitor from discharging when the pulse has passed. In this manner the voltage across the 47-microfarad capacitor increases with each incoming pulse. Approximately one one-thousandth of the incoming pulse is applied to the storage capacitor, this ratio being determined by the ratio of the 0.03-microfarad capacitor to the 47-microfarad capacitor. The 1N645 diode prevents the storage capacitor voltage from exceeding 8 volts. The voltage across the storage capacitor is applied to the grid of the CK5886 subminiature tube. The grid and cathode of this tube form a logarithmic diode, and the voltage across these elements is amplified by the tube and applied to the base of the 2N527 emitter-follower. A reference tube and emitter-follower are included to balance the drift in the circuit, the indicating meter being between the two emitters. The 10-K potentiometer provides zero adjustment, and the 10-K rheostat provides calibration adjustment.

When the selector switch S1 is in the "600 p" position, the storage capacitor does not discharge between successive pulses, and the output is a measure of the total number of pulses entering the counter. When the switch is in the "100 pps" position, the capacitor discharges through an 82-K resistor, and an equilibrium voltage is reached on the storage capacitor, depending on the leakage through the 82-K resistor and the rate of charge through the diode pump. In the "10 pps" position, the leakage from the capacitor is one tenth as great, and the meter reading is consequently 10 times as large. Full-scale reading in the "100 pps" position is 100 pulses per second, corresponding to ten million particles per cubic foot, undiluted. It is 0.1 times this amount in the "10 pps" position. In the "600 p" position, full-scale is obtained with 600 pulses, and with a counting period of 1 minute, this results in a full-scale reading of one million particles per cubic foot undiluted.

Pulse-Height Analyzer

When the pulse-height analyzer is used with the particle counter, the pulses from the amplifier "c" are applied to the analyzer through terminal A of connector C1. This point is connected to the sensitive channel amplifier. An emitter-follower, Q6, applies an unamplified pulse to the insensitive channel amplifier through terminal B of connector C1. The emitter-follower is used to provide lower output impedance and thereby to reduce

noise pickup on the cable. The block diagram of the pulse-height analyzer is shown in Figure 6, and a more detailed circuit diagram is shown in Figure 9.

The two inputs from the particle counter are applied to identical amplifiers. The sensitive channel amplifier applies pulses to the first eight channel discriminators, and the insensitive channel amplifier applies pulses to channels 9 through 12. The potentiometers at the input of the amplifiers are set so that the discriminator of channel 9 fires at the point where the sensitive channel amplifier becomes saturated. These two amplifiers are identical in operation to the amplifier in the particle counter; however, slight circuit changes have been made to accommodate the B+ voltage of 12 volts and the B- voltage of -22 volts, which are used in the analyzer. The amplifier circuit is shown in detail in Figure 10, which is the circuit of board No. 14.

The analyzer counts pulses in the same way as the particle counter with the refinement that the pulses are divided into twelve channels according to height. A thirteenth channel counts all the pulses as large as or larger than those entering channel 1. The method used to separate the pulses into the various channels is to apply a gate pulse, generated by each pulse entering the analyzer, to the gate circuit in each channel. The gate circuit of channel 1 is opened by the firing of discriminator 1 and closed by the firing of discriminator 2. The gate circuit of channel 2 is opened by the firing of discriminator 2 and closed by the firing of discriminator 3. Thus, only one gate circuit can be open for any one pulse. When a gate circuit is open, the gate pulse is applied to the counting circuit, and when the gate circuit is closed, the gate pulse is blocked.

To insure that the gate pulse will be generated while the input pulse to the discriminators is still present and is at its maximum value, the peak storage circuit stores on a capacitor the peak voltage reached by the diode pump circuit. The gate pulse generator is delayed until the storage action has taken place, and then the action of the gate pulse generator initiates the discharge of the storage capacitor. The peak storage circuit is shown in Figure 10. It is a diode pump circuit that uses 2 PNP transistors as low forward-drop diodes. The input pulses of the amplifier are stored on the capacitor, which is prevented from discharging by the diode-connected transistor. After the gate pulse has been generated, the

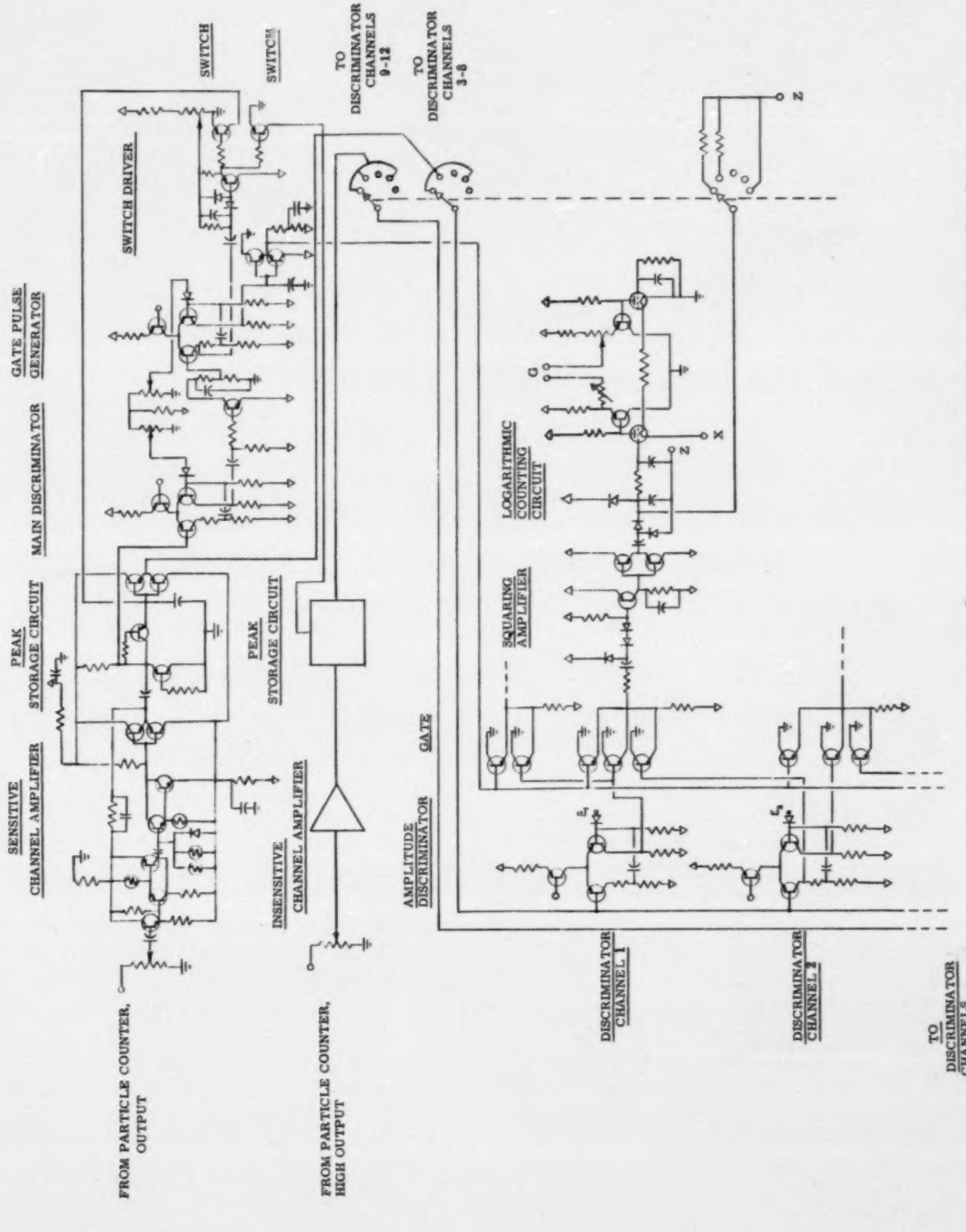
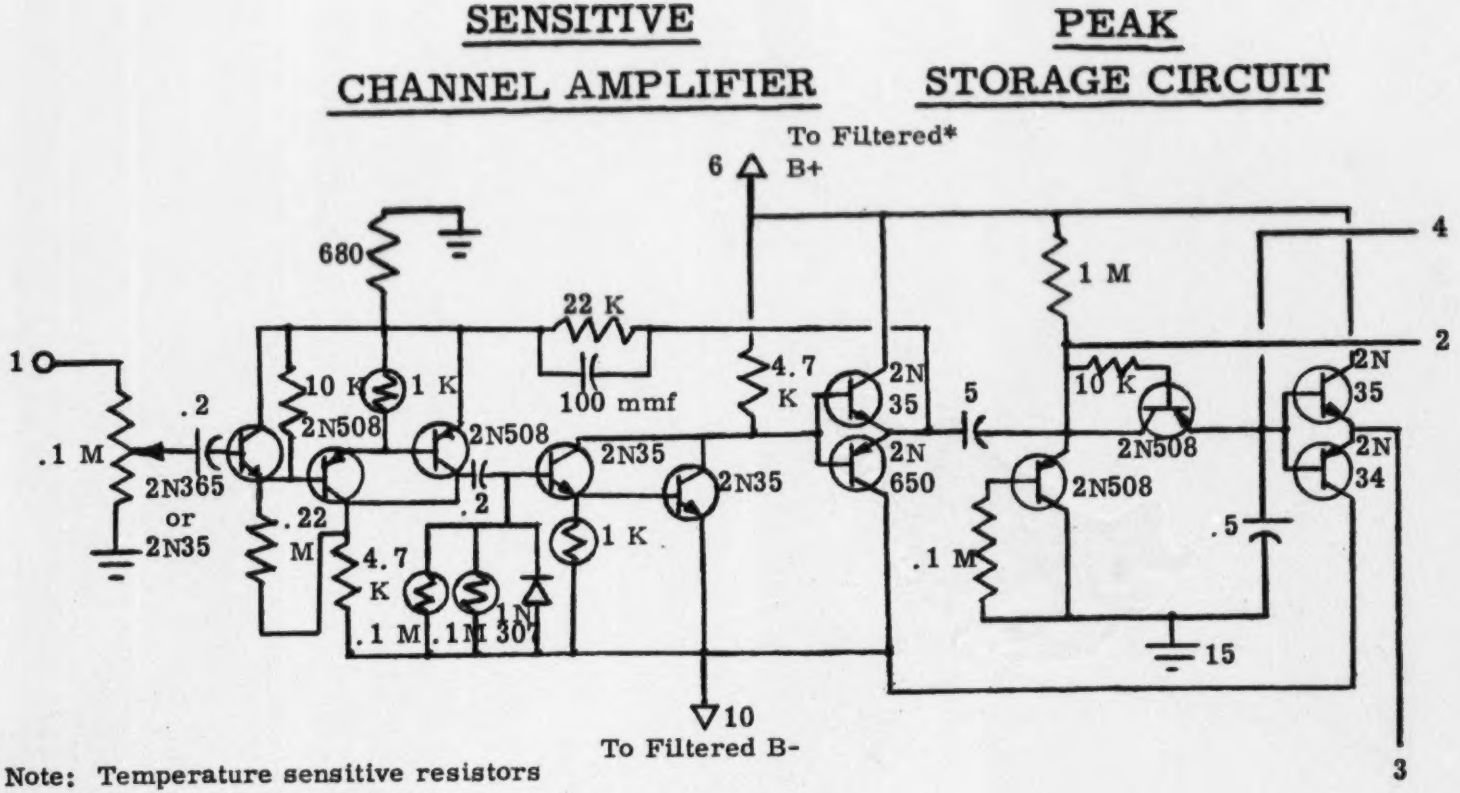


Figure 9. Circuit of the Pulse-Height Analyzer.



Note: Temperature sensitive resistors are Fenwal thermistors.

* Board No. 15 is connected Directly to B^+ and B^-.

Figure 10. Circuit of Board No. 14.

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switch circuit discharges the capacitor through terminal 4. The pulse from the storage capacitor is given power amplification by the complementary emitter-follower, which has its output connected through the selector switch to the discriminator input.

The pulse from the amplifier is also applied through terminal 2 to the main discriminator shown in detail in Figure 11, which is the circuit of board No. 16. This discriminator is identical in operation to the discriminator in the particle counter. Its reference voltage is set at about -0.5 volt to insure that all pulses large enough to fire one of the channel discriminators also fires the main discriminator. The output of the discriminator, a two-volt negative pulse, is differentiated by the 0.0015-microfarad capacitor, and the 0.1-megohm resistor. This results in a negative and positive spike, which is applied to the inverting amplifier Q4. Q4 amplifies only the positive spike, which becomes a negative pulse applied to the gate generator. These waveforms are shown in Figure 12.

The gate generator is another emitter-coupled clipper circuit identical to the main discriminator. The RC network between the inverting amplifier and the base of Q5 partially integrates the incoming spike and produces a triangular wave with a steep leading edge and a sloping trailing edge. The setting of the base voltage of Q7 therefore only slightly affects the time at which the generator fires but strongly affects the time at which Q5 cuts off. Thus, the potentiometer in the base circuit controls the pulse width, negligibly affecting the time at which the pulse begins.

The gate pulse is obtained from the collector of Q7 and is given power amplification by the complementary emitter-follower before being applied to the 13 gate circuits. The RC network, connected to the 2 emitters of the emitter-follower, filters out high frequency noise caused by the power supplies. The positive pulse formed on the collector of Q5 is used to drive the switches that discharge the 2 peak storage circuits. The switch driver and switches are shown in Figure 13, which is the circuit of board No. 17. The positive pulse derived from the gate generator is differentiated by the RC network, and the positive spike resulting is suppressed. The negative spike causes the emitter of Q1, which is normally slightly positive, to become negative. This allows the two switch transistors Q2 and Q3 to conduct, and the two storage capacitors are connected to ground. The potentiometer R1 is adjusted high enough so that the switch transistors do not leak during the storage period. If adjusted too high, however, the

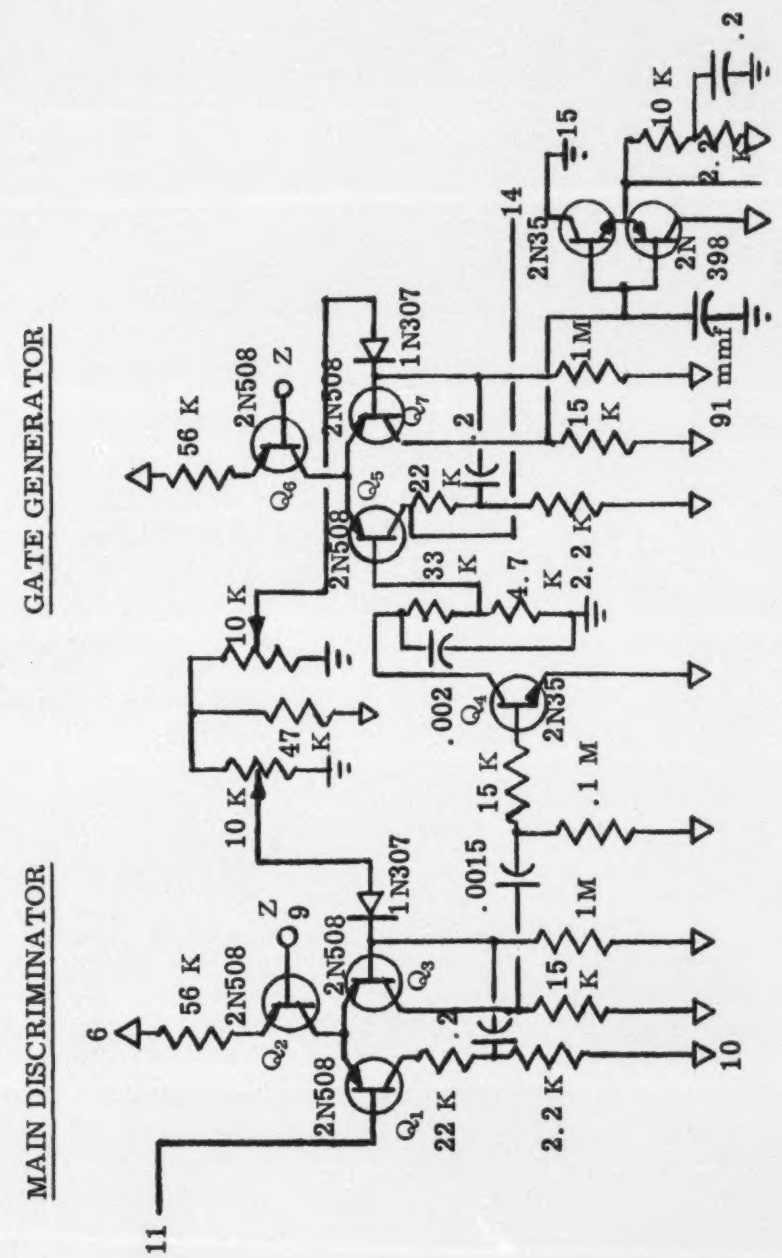


Figure 11. Circuit of Board No. 16.

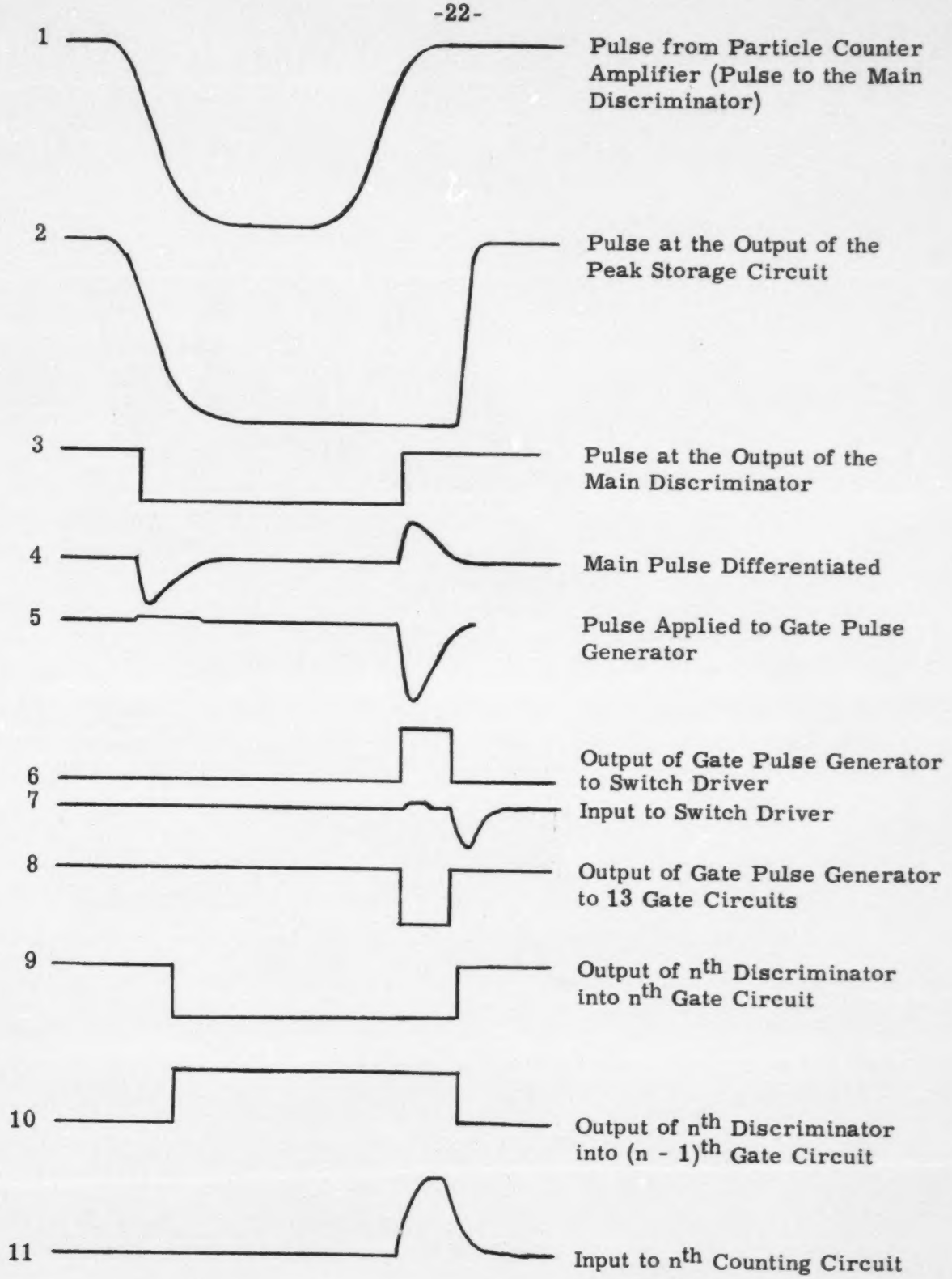

1
Pulse from Particle Counter Amplifier (Pulse to the Main Discriminator)
2
Pulse at the Output of the Peak Storage Circuit
3
Pulse at the Output of the Main Discriminator
4
Main Pulse Differentiated
5
Pulse Applied to Gate Pulse Generator
6
Output of Gate Pulse Generator to Switch Driver
7
Input to Switch Driver
8
Output of Gate Pulse Generator to 13 Gate Circuits
9
Output of nth Discriminator into nth Gate Circuit
10
Output of nth Discriminator into (n - 1)th Gate Circuit
11
Input to nth Counting Circuit

Figure 12. Waveforms in Analyzer Circuits.

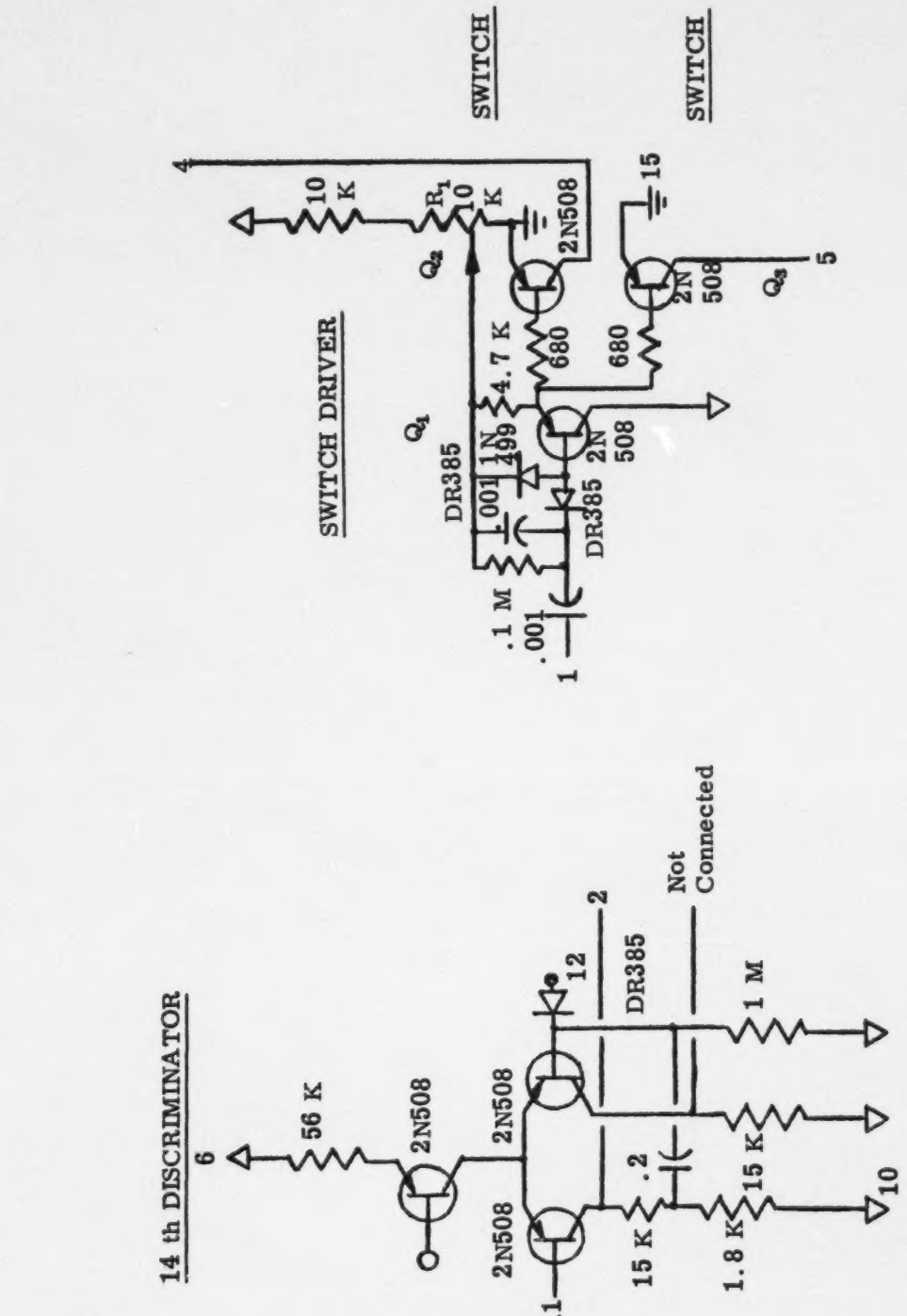
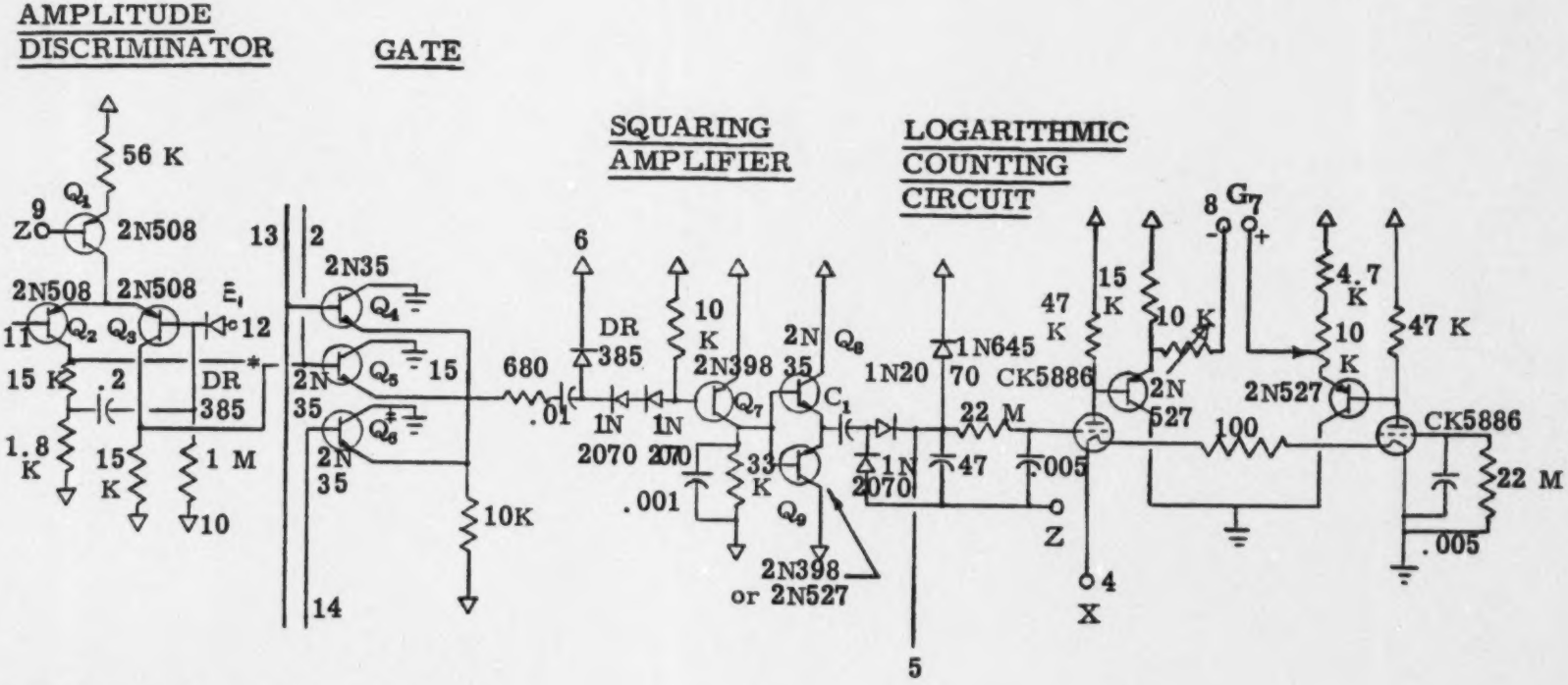


Figure 13. Circuit of Board No. 17.

capacitors will not discharge completely during the interval of switching. The two switch transistors must have similar characteristics so that they will both operate properly at the same setting of potentiometer R1.

The circuit of the first discriminator channel is shown in detail in Figure 14, which is the circuit of board No. 1. The circuits of the other channels are identical, except as noted on the figure and except for the value of C1. The discriminator channel circuit is identical in operation to the circuit in the particle counter, except that the gate pulse is counted and the amplitude discriminator is used to open and close the gate circuit. The incoming gate pulse is a negative pulse of about 2 volts on a d-c level of -20 volts. This d-c level holds Q4 in Figure 14 in a conducting state and allows a voltage drop of 2 volts across the 10-K gate resistor. The output of the discriminator taken from the collector of Q3 is also a -2-volt pulse on a d-c level of -20 volts. Q5 is therefore also normally conducting and will maintain the 3 gate emitters at -20 volts. The base of Q6 is connected to the collector of Q2 in channel 2 (not shown). Q2 is normally cut off and -22 volts appears on the base of Q6. This prevents Q6 from conducting. When a pulse from the amplifier is received large enough to fire discriminator 1, the base of Q5 goes from -20 to -22 volts, cutting off Q5. During the time that Q5 is cut off, a gate pulse will be received by Q4. This will also be a pulse going from -20 to -22 volts, cutting off Q4. If the pulse coming into the discriminators is just large enough to fire discriminator 1, but not large enough to fire discriminator 2, the voltage at the emitters of the gate circuit will follow the gate pulse and decrease from -20 to -22 volts. The gate pulse, and consequently the pulse to the counting circuit will be of about 200 microseconds duration. If the incoming pulse to the discriminators is large enough to fire discriminator 2, this action will cause the base of Q6 in channel 1 to rise from -22 to -20 volts, and Q6 will conduct. With Q6 in the conducting state, the emitters will remain at approximately -20 volts, even though Q4 and Q5 are cut off. Thus, the gate pulse will be blocked, and no pulse will be transmitted to the counting circuit.

Because the pulses to the 3 transistors of the gate circuit are not identical, and because these transistors have varying characteristics, small false pulses will appear on the emitters of the gate circuit when the gate is supposedly closed. These false pulses are prevented from reaching the squaring amplifier by the two voltage-dropping diodes in series with the



* Terminal 2 is used for this point on all channel boards except No. 1.

+ This transistor is removed on the Total channel board, No. 13.

Figure 14. Circuit of Board No. 1.

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base of Q7. Q7 is driven from an almost cut-off state to saturation by a true pulse, and its output is a positive pulse of about 30 volts. This pulse is given power amplification by the complementary emitter-follower composed of Q8 and Q9.

The counting circuit is essentially the same as that used in the particle counter; however, capacitor C1 is different for different channels to achieve approximately uniform full-scale concentration readings per 0.1 micron of particle size range. The total channel and the first three discriminator channels use a 0.02-microfarad capacitor to give a full-scale concentration reading of 10 million particles per cubic foot per 0.1-micron size range. Channels 4, 5, 6, 7, and 8 are 0.2 micron wide; and to obtain the same full-scale reading per 0.1 micron, use a value of C1 of 0.01 microfarad. Similarly, channels 9 and 10, which are 0.4 micron wide, use 0.005-microfarad capacitors, and channels 11 and 12, which are 0.8 micron wide, use capacitors of 0.0025 microfarad. The calibrating rheostats are adjusted to compensate for small differences in capacitance and other characteristics.

As in the particle counter, the storage capacitor in the diode pump circuit is connected to a switch to provide "100 pps," "10 pps," and "600 p" full-scale readings. The switch also has a "Hold" position to be used when recording data and a "Zero" position used to discharge the capacitors. This switch is a 5-position, 15-pole wafer switch. The input pulses from the 2 peak storage circuits are connected to the discriminators through this switch to allow these circuits to be opened when the switch is in the "Hold" and "Zero" positions. Pulses from the sensitive channel amplifier go through the first pole of the selector switch and are applied to discriminator channels 1 through 8 and to the ninth discriminator, which closes the gate of the eighth channel. The pulses from the insensitive channel amplifier go through the second pole of the selector switch and are applied to discriminator channels 9 through 12 and to the fourteenth discriminator, which closes the gate of channel 12. The wiring diagram of the switch is shown in Figure 15. The ninth discriminator is located on board 13, and the fourteenth discriminator is located on board 17.

The Reference Voltage String

The graph of Figure 2 shows the relationship between particle size and discriminator input voltage. Channel boundaries are also shown in the figure. The first curve is an extension of the second curve and its scale is consequently 0.1 times that used for the other two.

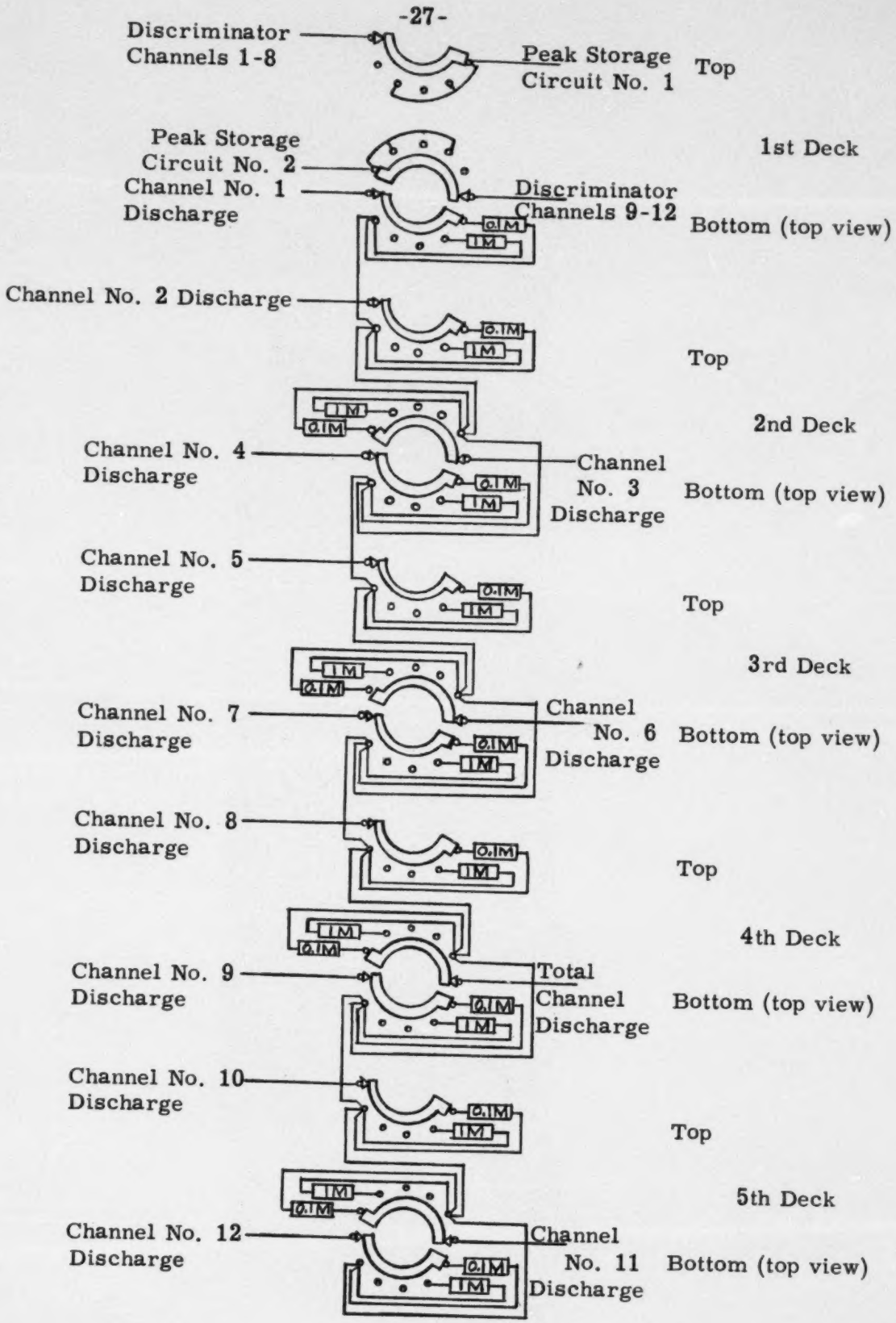

Figure 15. Selector Switch.

The reference voltages are obtained from the circuit of Figure 16. The reference voltage potentiometers are in series with a 100-ohm sensistor, which provides changes in reference voltage that compensate for changes in discriminator sensitivity with temperature. The wiring diagram of this circuit is shown in Figure 17. The reference voltages are adjustable over a short range by means of the potentiometer screws exposed at the top of the analyzer. Also exposed at the top of the analyzer is the adjustment for the main discriminator reference voltage and the gate pulse width adjustment. Care should be exercised to avoid turning these potentiometers by mistake when zero adjustments are being made.

The channel boundaries shown in Figure 2 are arbitrary and have been set to provide an approximately log-log display on the galvanometer face. The size range can be extended to 5 microns by adjustment of the reference potentiometers. The range can be extended to 10 microns by adjusting the input potentiometer to the insensitive channel amplifier and by making corresponding changes in the reference potentiometers. The input potentiometers of the sensitive and insensitive amplifiers are located on the respective amplifier boards 14 and 15.

The Power Circuits

The power required to operate both the particle counter and the pulse-height analyzer comes from the particle counter batteries located on the door of that instrument. These batteries are three LR10 silver-zinc cells and two 8-volt mercury cells. The three 1.3-volt mercury cells provide stable voltage references for the voltage regulator. The two 8-volt mercury cells provide B+ and B- voltage for the particle counter circuits.

The $4\frac{1}{2}$ volts from the silver-zinc batteries is used to drive the two power supplies in the pulse-height analyzer. These power supplies provide +12 and -22 volts for the pulse-height analyzer circuits.

The other voltages required by the particle counter and pulse-height analyzer circuits are provided by the batteries through the regulator shown in Figure 8. The regulator is a conventional degenerative regulator. As seen in the figure, a change in the negative output voltage with respect to the positive voltage will cause a corresponding change in the voltage of the base of Q7. A change of the opposite sign will appear on the base

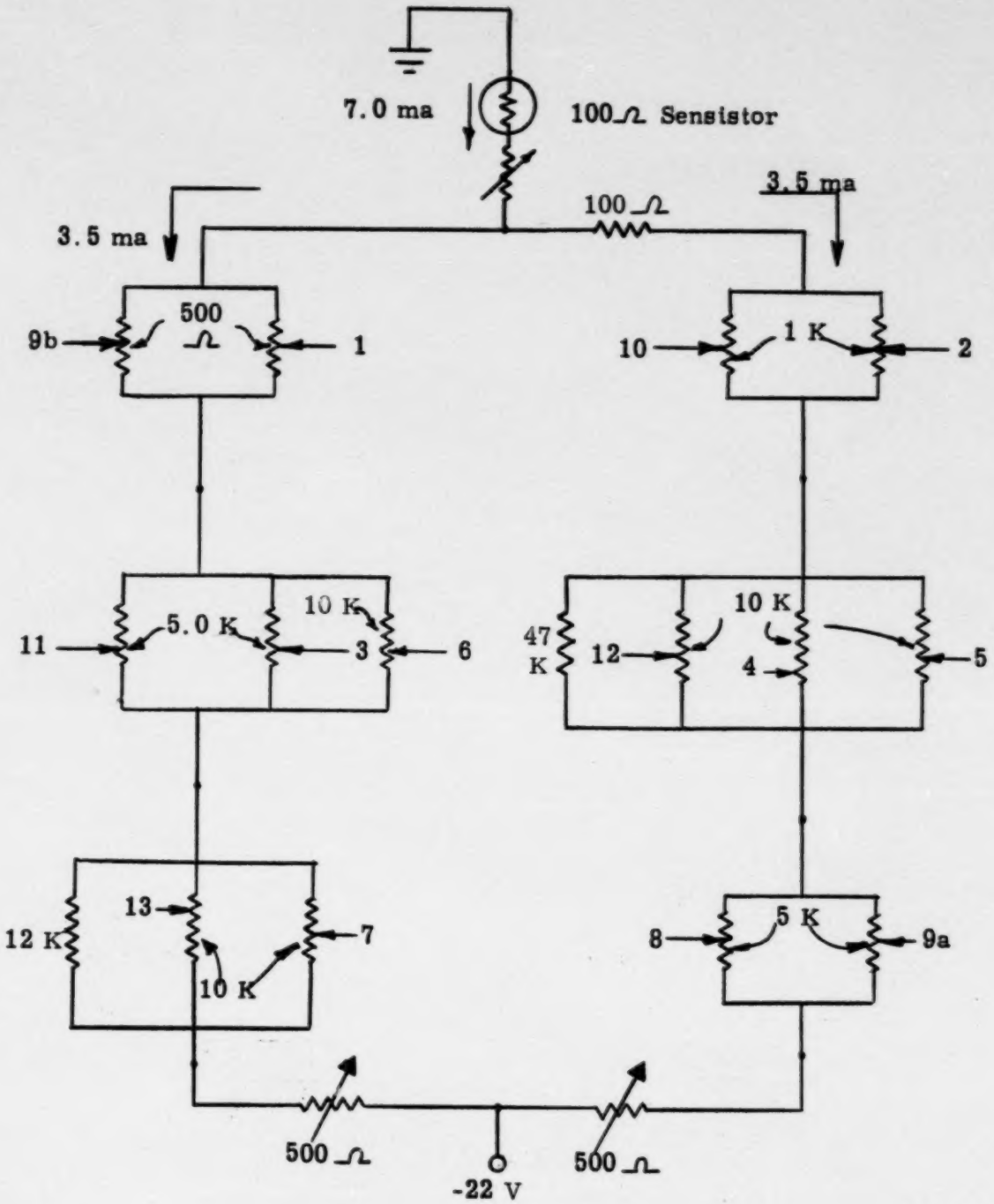

Figure 16. Reference Voltage Circuit.

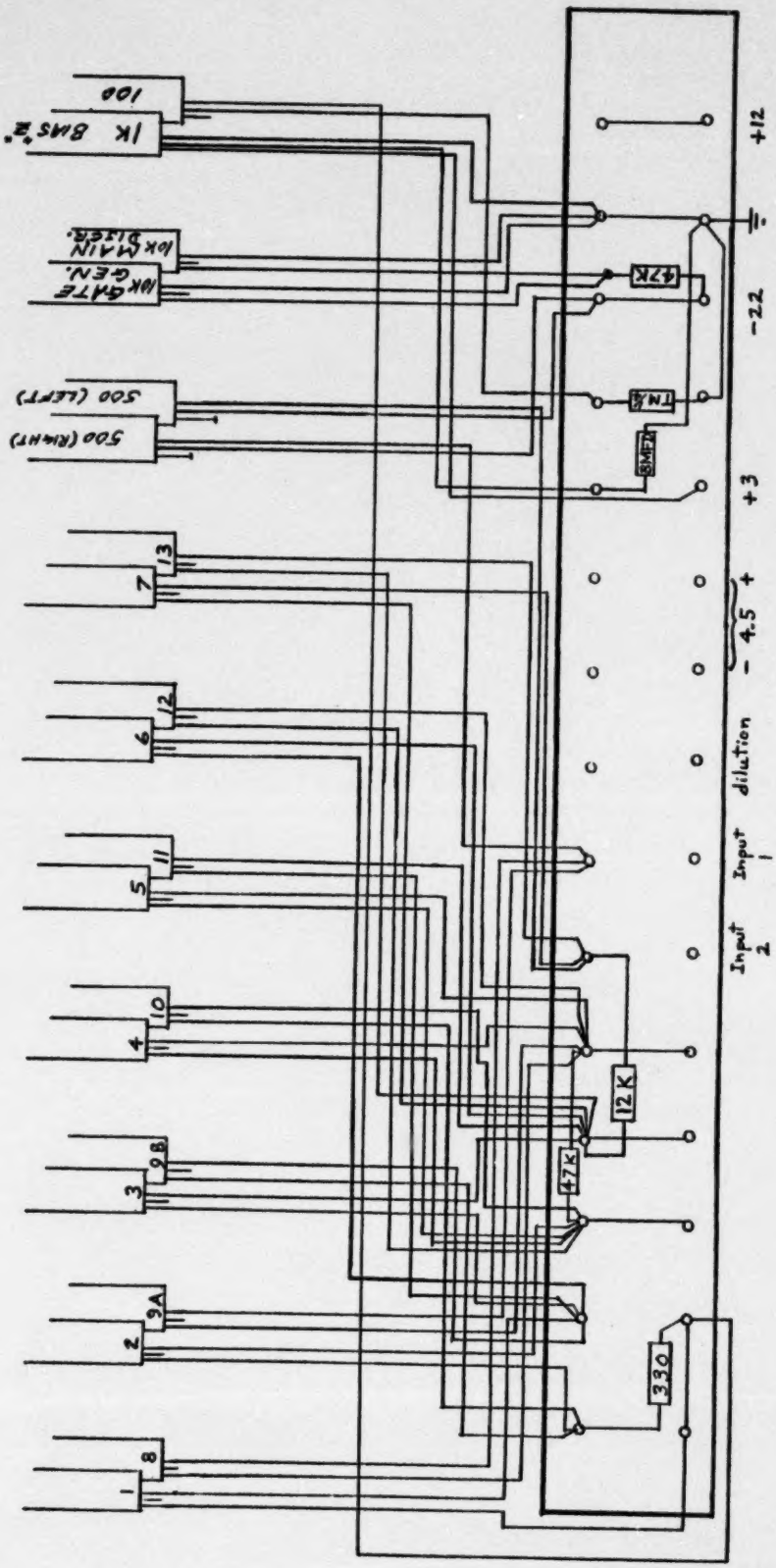

Figure 17. Wiring Diagram of the Reference String.

of Q8 and on the emitter of Q9, causing the original change to be compensated. Q10 provides temperature compensation for Q7, and the 2 silicon diodes act as a reference voltage source in the base of Q7.

The output of the regulator is 3.85 volts and is used to drive the pump motor, energize the illuminator lamp, drive the -900-volt power supply, and heat the filaments of the two CK5886 tubes. Besides providing these functions in the particle counter, the regulated voltage is supplied to the filaments of the tubes in the pulse-height analyzer and to the potentiometer that provides the bias voltage Z. A diagram of the power circuits of the pulse-height analyzer is shown in Figure 18.

A wiring diagram of the socket chassis is shown in Figure 19, and Tables 1 and 2 show the wiring of the connectors between the particle counter and the pulse-height analyzer and the connectors between the pulse-height analyzer and the 15-channel galvanometer.

The Galvanometer

The 15-channel galvanometer, Century Dynamic Monitor, Model 20-C, is modified to provide internal illumination of the transparent display grid and to permit photographing of the measurements. A 4 x 5 Graflok back is adapted to the front of the galvanometer and photographs can be made with either a Polaroid, Model 500, 4 x 5 Film Holder or with a 4 x 5 Graphic Film Pack Adapter.

The wiring of the lamp circuit in the 15-channel galvanometer is shown in Figure 20. The batteries, clamped to the sides of the galvanometer, provide approximately 5 volts for the galvanometer lamp and the grid-illumination lamp. The rheostat on the front of the galvanometer controls the brightness of both of these lamps and should be set to the lowest usable value to conserve the lamps and the batteries. The lamps are energized by the toggle switch S3 located on the front of the galvanometer. This switch is in parallel with a push-button switch S5 located on the front of the film-pack adapter plate. Switch S5 is available for pulsing the lamp circuits to obtain momentary exposure of film.

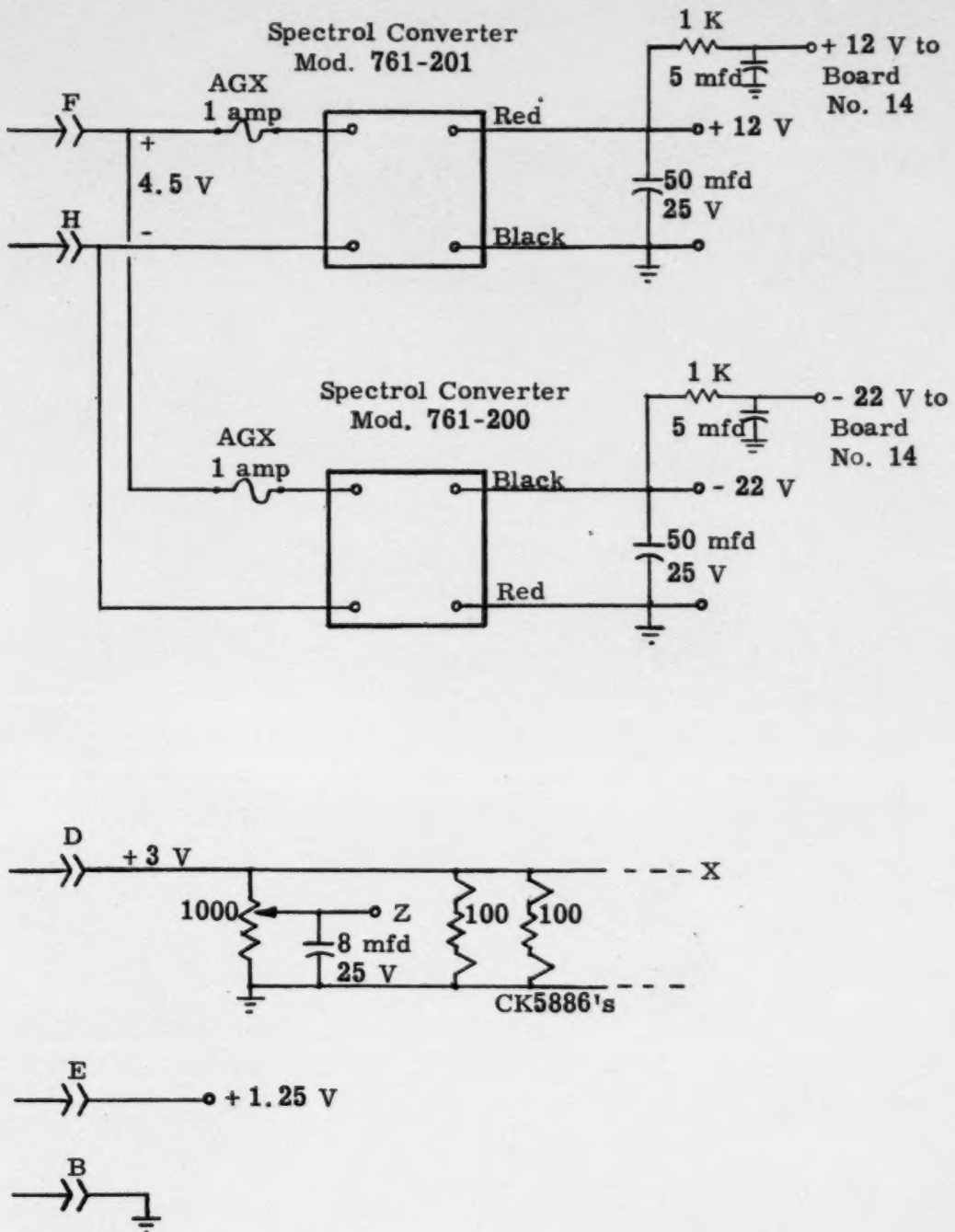

Figure 18. Power and Reference Voltage Circuits.

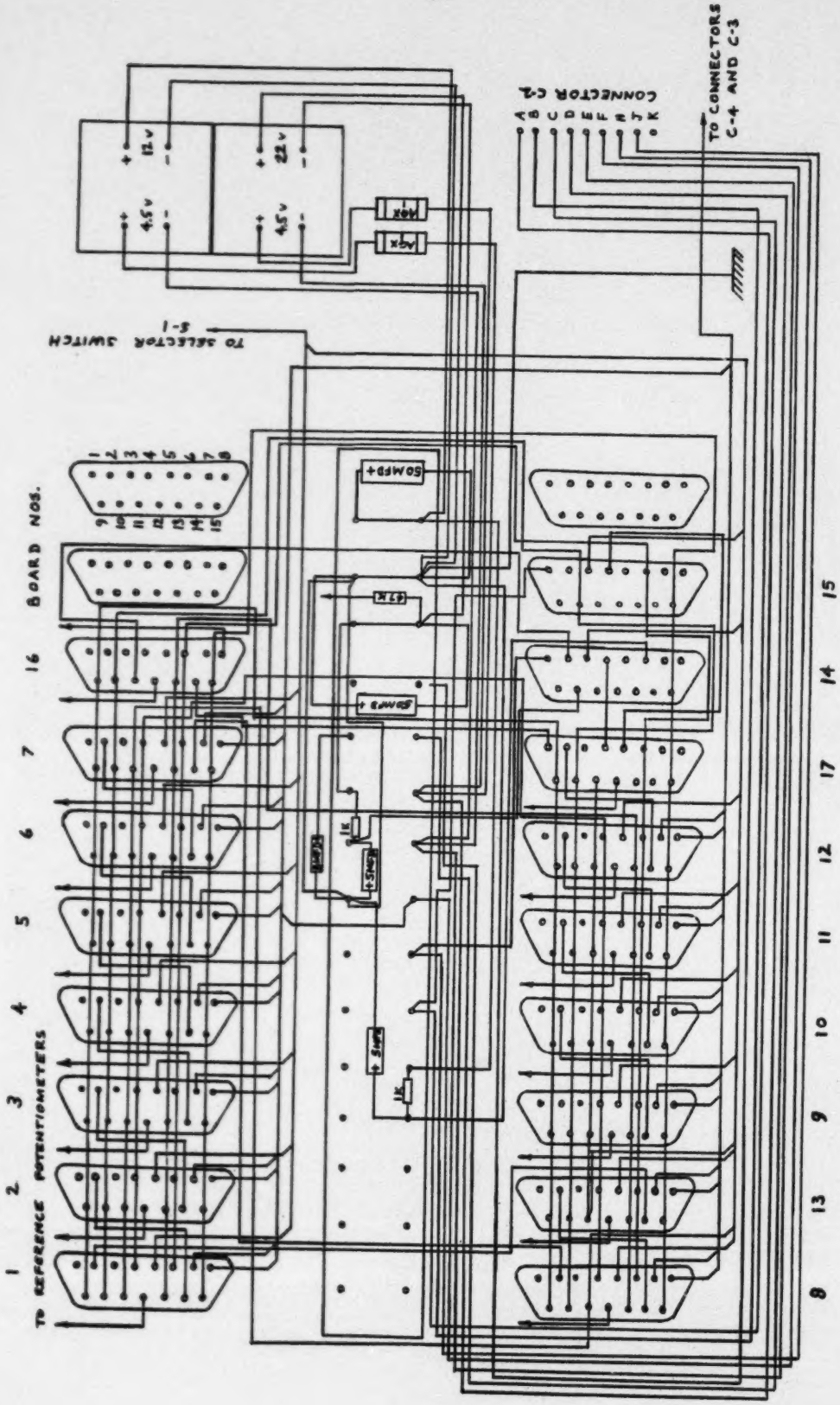
TO CONNECTORS C-4 AND C-3
CONNECTOR C-2
A B C D E F H J K
12 v
4.5 v
22 v
4.5 v
TO SELECTOR SWITCH S-1
1 2 3 4 5 6 7 8
9 10 11 12 13 14 15
BOARD NOS.
50MFD+
47K
1K
TO REFERENCE POTENTIOMETERS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Figure 19. Wiring Diagram of the Connector Chassis.

Table 1

Particle Counter to Pulse-Height Analyzer Connections

Connector Pin	Wire Color	Function
A	Red (Shielded)	Input No. 1 (to sensitive channels)
B	Black (Shielded)	Ground
C	Green (Shielded)	Input No. 2
D	Green-White	+3 volts
E	Yellow	+1.25 volts
F	Red (Large)	+4.5 volts) Ungrounded
H	Gray (Large)	-4.5 volts)
J	Gray (Small)	Dilution Factor

Table 2

Galvanometer Connections

Analyzer Connector	Terminal No.	Galvanometer Connector (Viewed from Rear)	Terminal No.	Galvanometer No. *	Color	Analyzer Channel No.
Top	1		E	3+	brown	
	2	Right	F	3-	brown and white	1
	3		H	4+	red	
	4	Right	J	4-	red and white	2
	5		K	5+	orange	
	6	Right	L	5-	orange and white	3
	7		M	6+	yellow	
	8	Right	N	6-	yellow and white	4
	9		P	7+	green	
	10	Right	R	7-	green and white	5
	11		A	13+	blue	
	12	Left	B	13-	blue and white	6
	13		C	14+	purple	
	14	Left	D	14-	purple and white	7
	15	Right	b		black	
Bottom	1		E	15+	brown	
	2	Left	F	15-	brown and white	8
	3		C	2+	red	
	4	Right	D	2-	red and white	Total
	5		H	16+	orange	
	6	Left	J	16-	orange and white	9
	7		K	17+	yellow	
	8	Left	L	17-	yellow and white	10
	9		M	18+	green	
	10	Left	N	18-	green and white	11
	11		P	19+	blue	
	12	Left	R	19-	blue and white	12

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Table 2 (Continued)

Galvanometer Connections

Analyzer Connector	Terminal No.	Galvanometer Connector (Viewed from Rear)	Terminal No.	Galvanometer No. *	Color	Analyzer Channel No.
Bottom	13	Left	Y		white	
	14		A	1+	gray	Dilution
	15	Right	B	1-	black	Ground
	-		S	8+	-	-
		Right	T	8-		

* See page 5 of Century Operating Instruction Manual, Dynamic Monitor, Model 20.

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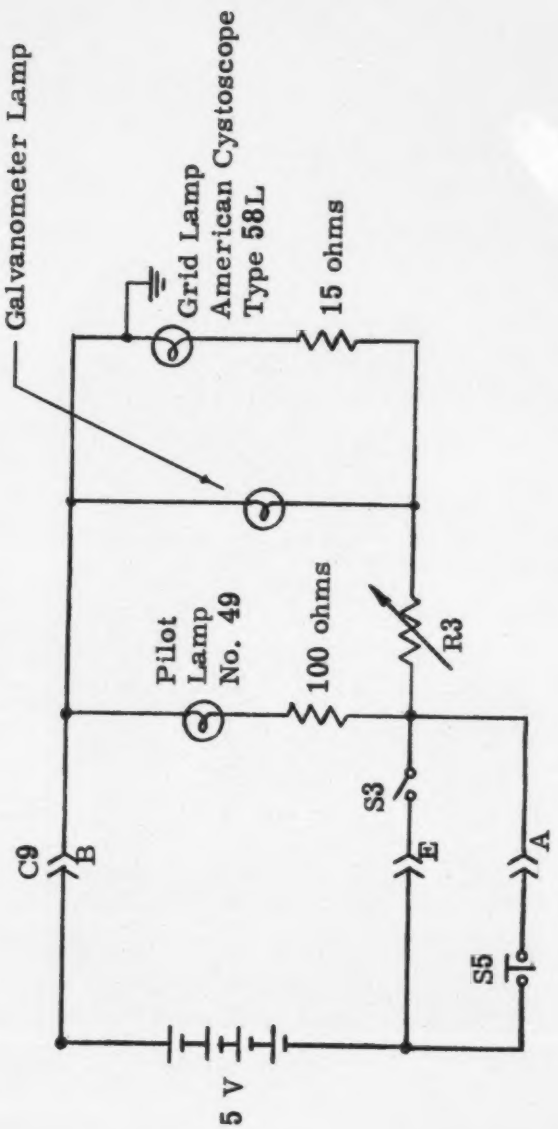

Figure 20. Lamp Circuits.

The galvanometer grid is approximately logarithmic in both directions. The vertical axis is calibrated to give millions of particles per cubic foot per 0.1 micron, diameter, bandwidth. Each channel is individually adjusted and is set so that channels covering a 0.2-micron size range will have one half the sensitivity of channels that cover only 0.1 micron. Channels covering 0.4 micron have one fourth the original sensitivity, etc. The boundaries and bandwidths of the channels are spread along the horizontal axis as shown in Figure 2. Integral bandwidths were chosen to provide ease of handling and interpreting data. However, the bandwidths were selected roughly logarithmically so that the light spots would be suitably distributed on a log-log distribution of concentration per unit size versus size. The log-log distribution will be only approximate because of the imperfect pulse rate scale.

SECTION VII. CALIBRATION

Calibration of the concentration scales of both the particle counter and the analyzer is based on an air flow of 17 cubic centimeters per minute through the potentiometer. The particle counter and the first three channels and the "Total" channel of the analyzer are adjusted to give full-scale reading when an input of 100 pulses per second is applied. Calibration pulses can be applied to the amplifier input. Full-scale reading with an input of 100 pulses per second applies only to the "100 pps" position and applies only to the particle counter and the "Total" and the first three discriminator channels of the analyzer. Channels 4 through 8 should read 5.0 million particles per cubic foot when 100 pulses per second are applied, channels 9 and 10 should read 2.5, and channels 11 and 12 should read 1.25. When in the "10 pps" position, the output should be 10 times that of the "100 pps" position. In the "600 p" position, the counting circuits continually add the incoming pulses; and for these readings to be meaningful, the counting time must be measured. For a counting time of 1 minute, full-scale reading corresponds to one million particles per cubic foot per 0.1 micron. One million particles per cubic foot with a flow rate of 17 cubic centimeters per minute corresponds to a rate of 10 pulses per second. This is equal to 600 pulses per minute, and therefore in the "600 p" position, the particle counter, the "Total" channel, and the 0.1-micron channels should read full-scale on 600 pulses. Wider channels should read correspondingly less.

The channel boundaries, which give rise to the x-axis calibration and which are shown in Figure 2, are determined by the reference string voltages. The curves of Figure 2 show the relative voltages among the channel boundaries and can be used to set these boundaries. If the vertical scale is considered to begin at 0.010 volt, it corresponds to the pulse height at the output of the phototube required to exceed the various boundaries. Thus channel No. 1 should count when the pulse height exceeds 0.008 volt and should stop when the pulse height exceeds 0.016 volt. Since the output to channels 9 through 12 is 0.1 times that to channels 1 through 8, the ninth channel should count when the pulse height exceeds 0.12 volt and stop when the pulse height exceeds 0.16 volt. To apply calibration pulses, disconnect the shielded lead from the phototube to the amplifier board and connect a pulse generator to this point on the board.

SECTION VIII. MAINTENANCE SUGGESTIONS

Batteries

The 8-volt mercury batteries are Mallory type TR136R cells. They have an expected operating life of about 200 hours and should be replaced when the voltage under load decreases to 7.5 volts.

The 1.3-volt mercury batteries are Mallory type 2ZM9 cells. They have an expected operating life of about 600 hours and should be replaced when the voltage under load decreases to 1.25 volts.

The 1.5-volt silver-zinc batteries are Yardney type LR10 cells. Under the combined load of the particle counter and pulse-height analyzer they will discharge in about 4 hours. For charging rates and other maintenance suggestions, see the Yardney literature. The battery charger furnished will charge the LR10 cells at 0.5 ampere, and full charge is noted by a rise in terminal voltage to 2.1 volts per cell or 6.3 volts.

The 1.2-volt nickel-cadmium batteries are Nife type CM-4.4 cells. They are 4.4 ampere-hour cells and will discharge in about $2\frac{1}{2}$ hours. They should be charged to 6.2 ampere-hours at a rate of less than 1.2 amperes.

The battery charger furnished with the instrument has separate pairs of leads to provide simultaneous charging of the silver-zinc and

nickel-cadmium batteries. The 500 ma leads should be connected to the 3 silver-zinc batteries in series, and the 300 ma leads should be connected to the 4 nickel-cadmium batteries in series. This will provide full charging of both sets of cells in 24 hours.

During laboratory use of the instrument it is suggested that an auxiliary power supply of 4.5 volts be used in place of the silver-zinc battery. Connection to the particle counter can be made by removing the particle counter fuse and plugging the auxiliary voltage into the charging connector located on the rear of the counter. Failure to remove the particle counter fuse will cause the batteries to be subjected to the supply voltage and might cause over-charging and permanent damage.

It is also suggested that, in the laboratory, the galvanometer lamps be supplied from a 6-volt filament transformer. Before doing this, the leads to the batteries should be disconnected, and the lamp intensity rheostat should be turned down.

Lamps

The illuminator lamp is a General Electric type PR-3 lamp and has an expected operating life of about 35 hours. However, it may be necessary to replace the lamp before it has burned out because of darkening of the bulb. This will be indicated by a lowered reading of the illumination-detector meter, and can be confirmed by testing the analyzer or particle counter response to standard size polystyrene spheres. Before suspecting the lamp, the battery voltages should be measured.

The galvanometer lamp is a 6-volt lamp made by Chicago Lamp Company. Replacement procedures are discussed in the Century instruction manual.

The grid illumination lamp is a type 58L lamp manufactured by the American Cystoscope Makers, Inc. It should last indefinitely at moderate

intensity settings. To replace this lamp, the lamp bracket must be removed, and a soldered connection must be made to the base of the new lamp.

ACKNOWLEDGMENT

The optical and mechanical design of this instrument was conducted by Mr. Alvin Bird, Associate Physicist, and much of the electronic design was conducted by Mr. Preston Rice, Assistant Electronics Engineer.

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Birmingham, Alabama
October 12, 1959
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PULSE GENERATOR